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ULTRASONIC NONDESTRUCTIVE INSPECTION ON XM650 ROCKET ASSISTED P--ETC(U)

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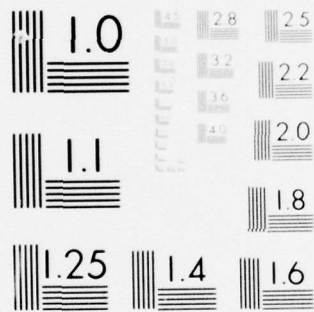
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TECHNICAL MEMORANDUM ARPAD-MR-77002

ULTRASONIC NONDESTRUCTIVE INSPECTION
OF XM650 ROCKET ASSISTED PROJECTILE
FOR BONDING QUALITY OF THE ROTATING BAND

JAY S. PASMAN

JULY 1977



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
PRODUCT ASSURANCE DIRECTORATE
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Specification testing of the rotating bands on the XM650 Rocket Assisted Projectile (RAP) failed to screen out inadequate bonding. This report covers the development of an ultrasonic C-scan inspection as a reliable nondestructive technique to identify poorly bonded bands. The system depends on the use of a standard motor body with a known defective area for daily equipment setup and calibration. A government furnished C-scan of this rotating (Cont on p 1473B)		

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20. ABSTRACT (Continued)

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band delineates the exact area which the in-plant inspection must depict, and contains guidelines for the visual reject level. There have been no band failures in the 264 flight tests since this procedure has been implemented.

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INTRODUCTION

The XM650 is an 8-inch rocket assisted projectile (RAP). The motor body contains a copper rotating band produced by a welded overlay process. During early test firings in the engineering development program, band failures were experienced as the shells emerged from the gun tube, resulting in a substantial reduction in flight distance.

It was evident that the specification testing had not been capable of detecting inadequate bonding in these shells. The method used consisted of hardness testing and chemical analysis of machining chips, followed by sampling for destructive testing. Because the welding process is affected by minute changes in operational parameters, a nondestructive procedure capable of full area inspection of all shells produced is obviously desirable.

An investigation of various testing techniques indicated the desirability of an ultrasonic C-scan procedure which had been initiated and developed at Picatinny Arsenal for an earlier brazed rotating band on the XM517 projectile (Ref 1 and 2). This technique, although successfully established, did not reach implementation and firing verification because the XM517 program was canceled. Application to the XM650 program, however, required further feasibility and development due to the heavily cratered interface between the copper and steel created by the welding process employed in this program. Similar earlier efforts at another installation were unsuccessful because signals from unbonded areas were masked by reflections from this desirable cratering, which indicated good steel penetration. Thus, follow-up statistical firing verification takes on added significance in the XM650 program. It becomes even more important since motor bodies manufactured in this program are being used in the development of the more sensitive XM753 RAP program.

For these reasons, it was considered essential that the hundreds of previously built motor bodies, although having passed acceptance inspection, be screened, followed by firing data feedback. Furthermore it would be necessary, and feasible for the first time, to establish a tolerance level for poorly bonded areas. Also, this laboratory investigation provided a secondary benefit in providing a rapid assist for improvement of the quality of the welded overlay process. Similarly, in application, this inspection will be used for immediate feedback in process control to improve economy and reliability.

DESCRIPTION OF TEST COMPONENTS

The copper rotating band on the XM650 RAP is deposited, in a molten state, on the motor body by a welded overlay process. It is then machined to the contour shown in Figure 1. The band is a nominal 2 inches (50 mm) wide by 1/16 inch (1.6 mm) thick at the root of its cannellures. However, the thickness may range down to a few thousandths of an inch, considering normal dimensional and eccentric tolerances, as well as steel migration caused by the overlay process. Below the rotating band, the hardened steel body is 1/2 inch (13 mm) thick.

During earlier development, the welded overlay was produced by a process known as MIG welding. However, because of anticipated cost savings, a switch was made to plasma-arc welding. Units produced by the latter process passed the prescribed testing, but then encountered the loss of band segments during firing. Therefore, the development work covered by this report was initiated and concentrated principally on plasma-arc welded bands. A decision was made late in this investigation to revert to MIG welding. Therefore, the ultrasonic inspection detailed in this report was confirmed for applicability to the MIG-welded overlay bands.

The difference in the two welding methods is significant because of the nature of the copper-steel interface produced by each. With the desired degree of steel penetration, MIG welding results in a steel surface covered by small individual craters; the plasma-arc process creates a surface with a series of "puddling" grooves following the arc path of the electrode. Care must be exercised so that this difference does not affect the C-scan inspection.

A more complete description of the evaluation of the two welding procedures may be found in Reference 3.

TEST EQUIPMENT

The equipment used in this investigation is known as an ultrasonic C-scan system. It consists of a standard ultrasonic flaw detector with its output in the form of a lay-out chart or plan view of the surface of interest. The technique used was pulse-echo water immersion.

The ultrasonic equipment consisted of a Sperry UM-721 reflectoscope containing a 10N Pulsar/Receiver, a Type H Fast Transigate, and a Type S recording amplifier. The transducer used was an Automation J388. This is a cylindrical ceramic transducer with a 1/4-inch (6.3 mm) diameter crystal and a focused lens with a 2.2-inch (50 mm) focal distance in water. It was operated at 10 MHz.

The complete system is shown in Figure 2. The lower section, a cabinet and stand, supports the apparatus. Centered on the cabinet is a glass-walled water tank with a 12-inch (300 mm) motor-driven turntable on which an XM650 motor body is positioned. The recording drum (on the right) is synchronized to rotate with the turntable. The stylus steps vertically, synchronized with the transducer-holding search tube located just above the shell in the water tank. In this program, a rotary speed of 30 rpm and a vertical indexing increment of .045 inch (1.1 mm) per revolution scanned the rotating band in less than 1.5 minutes. The recording illustrates a generally good bond condition with only one rather large unbonded area. Another C-scan of a band with flawed bonding is shown in Figure 3. The chart paper is wide enough to permit recording the scans of three motor bodies on each sheet.

TEST METHODS AND RESULTS

The program consisted of the following sequence of steps:

1. Establishing Operating Parameters and Confirmation

a. The first effort required experimental work to locate a banded body with a limited section of inadequate bonding, one that would be typical of the problem and that could be used as a standard. It was important to identify accurately the exact contour and area encompassed by the unbonded action. (It should be noted that a minor change in sensitivity could have a significant effect on the apparent defective area; thus, it was essential to establish the true perimeter, and the optimum equipment settings required to obtain the same.) This "lab standard" would then be used to assure repeatability on the same equipment and between other setups projected for use at contractors' plants, and to establish "contractor standards." The selection of a lab standard is complicated by the inability to confirm the flaw pattern by another nondestructive method.

b. Selecting a standard was accomplished empirically from a group of non-fired shells of the same lot which had lost band segments during firing. Once several shells were located (using C-scanning) with areas resembling that on failed bands, experimental setting levels were optimized. These settings were confirmed by:

(1) Scanning five fired shells which had band segments missing. The C-scans indicated adjacent areas of poor bonding. These areas were lifted with a hammer and chisel until the limit of the unbonded area was established. The physical size showed excellent correlation with the C-scans.

(2) From the non-fired group, a pair of shells with similar appearing flaw areas, which were not too extensive, was selected. One was set aside as the prospective lab standard. The second was scanned at a series of equipment settings ranging from a 10% to a 70% threshold level, producing C-scans of varying size "flaw" indications. The copper band was then carefully removed from the shell body to permit correlating the pattern of the unbond to that shown on its C-scan. This was accomplished by initially cutting away the copper on a lathe to a .005-inch to .010-inch (.13-mm to .26-mm) thickness. By following this with a series of very light cuts, the shearing action of the cutter tears away most of the unbonded area (Fig 4). Because of eccentricity, it was necessary to etch away the balance of the copper chemically. Frequent observation during the etching process revealed the extent of the unbonded area with reasonable accuracy. Selection of the C-scan most closely resembling this area established the test parameters to be used on further verification studies.

2. Development and Use of the Lab Standard

Having established the exact size and location of unbond in the shell to be used as the lab standard, three flat-bottomed holes were drilled through the outside diameter of the copper down to the copper-steel interface. The holes were 3/16 inch (4.8 mm), 1/8 inch (3.2 mm) and 1/16 inch (1.6 mm) in diameter, respectively, and placed 1 inch (2.5 cm) apart along a centrally placed circumference of the rotating band in an area totally devoid of flaws. The size and placement of the holes were selected to facilitate setting up the equipment. The two larger holes assisted in expeditiously locating the alignment of the transducer.

The 1/16-inch (1.6-mm) diameter hole and the natural flaw pattern in this standard are considered to be the key items which enhance this inspection procedure, making it unique and highly repeatable. It has been amply demonstrated that sizing the hole exactly to the beam diameter at focal distance, or slightly smaller, permits much

greater sensitivity in precisely aligning the transducer and setting the pulse amplitude on the cathode ray tube than the 1/8-inch (3.2-mm) diameter hole more commonly used.

Similarly, the natural flaw pattern on the lab standard has been found to be highly sensitive to deviations from the optimum setup. In the course of this investigation, nearly 1000 shells were scanned. The standard was used to certify the setup before and after each set of runs, with a maximum of three hours of operation between certifications. On many occasions the flaw pattern indicated a significant variation which was, without exception, caused by some minor mechanical or electronic maladjustment. Most important, this was invariably easily discerned on the standard flaw pattern, and almost never detectable by the three-hole pattern.

3. Verification of the Prescribed Technique

The ultimate proof of the validity of this inspection procedure is its impact on successful flight tests. Because of the high cost of firing 8-inch shells, and the cost and time required by recovery and inspection, special firings to establish this inspection method have not been deemed practicable. Furthermore, it was considered unnecessary to alter the established development schedule of this weapon. Supporting information gathered to date:

a. A group of 19 motor bodies was especially prepared to evaluate proposed inspection techniques. Seven inspection categories ranged from no bond at all through light, medium, and heavy penetration of the base metal, and included intermittent welding. All bodies were correctly identified except the seven containing varying degrees of weld penetration exceeding .010 inch (.26 mm), all of which were identified only as good bonds.

b. As the program progressed, the copper bands were removed from selected samples. The contours generally followed the pattern seen on the C-scan, although in many cases the flaw area appeared to be slightly smaller than on the C-scan chart. This is believed to be caused by a transitional zone where the bond is of marginal quality.

c. Of the shells made in earlier lots (similar to those in which flight problems were encountered), a total of 572 were inspected. The poor category numbered 131 shells, or 23%. This is in general agreement with the 10% to 20% flight failure rate which initiated this investigation.

d. Since the inception of this program, 264 shells have been test fired in three separate series of tests, after those containing the poorest bonding were removed. Not a single short-range flight which could be attributed to band lifting has been experienced, nor have any of the recovered shells lost any band segments. The three series of test firings were:

(1) 54 motor bodies rated Fair to Excellent fired in Zones 8 and 9.

(2) 76 motor bodies selected as being only of the best quality, Good to Excellent, tested in high zone flights in the XM753 program. On the basis of this series, C-scan ultrasonic inspection is being recommended to the Safety Committee as a suitable procedure for the XM753 program.

(3) The third series consisted of 134 firings as listed below:

<u>Zone</u>	<u>Fair to Excellent</u>	<u>Marginal</u>	<u>Psp^a</u>	<u>Poor^b</u>	<u>Total</u>
1	--	--	6	1	7
3+	27	7	1	2	37
6	2	6	1	--	9
7	30	13	7	--	50
8	--	--	--	6	6
9	16	1	2	1	20
SZ-9 ^c	5	--	--	--	5

^aPsp, defined as poor because of starting pass only.

^bThe worst bodies in this category were not included in the chart nor in the firings.

^cSuper-Zone 9 - higher pressure in gun tube.

In analyzing the above chart, it should be noted that the primary purpose of testing was engineering development, concerned with other considerations. Thus:

(a) The concentration of the poorer quality was in the lower zones.

(b) The inclusion of two Psp bands in the Zone 9 firing was not considered serious, since poor bonding in this area was generally less extensive and more likely to include transitional bonds. (See paragraph (3), footnote b, above.)

(c) The worst bodies in the Poor category were not included in the firing program.

(d) Only good bonding was included in the Super-Zone 9 group.

It may be seen that only a very limited number of the "P" category were included in the tests and, with only one exception, all in the lower zones. Thus, there was only one Zone 9 firing that might have been expected to fail.

e. One rejected body, when subjected to a flight-level spin test, had the band fail in exactly the location and area anticipated from the C-scan.

f. Sixteen fired motor bodies were examined before and after firing, both visually and ultrasonically. There was no band lifting, nor any growth in the minor unbonds that had been considered passable.

4. Development of a Grading System

Initially a laboratory grading system of five categories was used. As more shells were examined, new categories were added to specify conditions believed to be borderline and to identify flaws primarily associated with the starting pass of the weld, as distinguished from extensive areas of poor weld penetration. For use as an acceptance inspection, the grading has been reduced to two levels: "accept" and "reject." The reject level now includes flaws which are considered possibly borderline; it is anticipated that this group may be upgraded at a later date.

5. Weld Process Improvement/Forging Inspection

A parallel effort was conducted during the course of this program to assist in the improvement of the welding overlay process. Rapid scanning enabled the contractor to evaluate variations made to his welding process.

Examination of the shells was conducted in the "forging" configuration; that is, prior to final machining. The experience gained was used to specify inspection at this stage of manufacture. The advantage of immediate feedback for process control is obvious, as well as

its eliminating additional processing of defective units. Also, the thicker copper at this stage permits a wider tolerance in the settings of the ultrasonic equipment. This permits less critical setup and less sensitivity to electronic drift.

Shells were examined to show that final machining had no effect on the displayed bond quality. However, heat treatment did open up flaws in some shells, believed to be due to marginal bond quality. Thus, inspection was specified to be conducted after heat treatment only.

6. Issuance of Calibration and Operating Instructions

After extensive revisions based on evaluation of many motor bodies, the first set of procedures was incorporated into an existing contract on an "informational" basis, (Ref 4 and 5). The informational concept requires that all motor bodies be scanned and graded, but not rejected at this initial stage. Rejectable bodies will be used for less severe tests, which should preclude malfunctioning. Process control feedback has demonstrably held the number of units in this category to a very low count, as detailed in the Discussion Section of this report. The decision to implement the ultrasonic C-scan inspection in this manner was made to correct the bonding problem as quickly as possible, and with a minimum cost impact.

The substance of the instructions, other than routine equipment setup, is as follows:

a. The initial standard, designated the "lab standard," will be retained by ARRADCOM at the Dover site to provide "contractor standards" for use at the manufacturing plant and to provide correlation between C-scans conducted at the Dover site or elsewhere. The contractor standard is a motor body which must be of identical physical properties and configuration as that used on the production run and contain an unbonded area of light weld penetration of approximately 1 to 2 square inches (6.5 to 13 cm²). Flat-bottom holes are drilled to the copper-steel interface and C-scans are furnished indicating an optimum scan, as well as upper and lower limits to which validating runs are acceptable.

b. The contractor standard is used to set up the inspection equipment each day to verify electronic stability and to detect mechanical maladjustments. Conducting standard scans before, during, and after inspection testing validates the accuracy of the inspection scans. These validation runs are required at periods not to exceed 4 hours.

c. Acceptance is based on the overall appearance of the band with exhibits to serve as guidelines. The fundamental concept is that any unbond shall be rejected if a linear measurement exceeds 1 inch (2.5 mm) across its surface. Some exceptions are permitted, based on the nature of the band failures experienced and on centrifugal stress calculations. The accept-reject criteria are considered the best bases at the present time to assure good flight reliability. As additional experience is gained, it is anticipated that the criteria will be revised prior to incorporation into a new contract as a mandatory acceptance test.

DISCUSSION

The material included in this report shows the current status of C-scan bonding inspection and includes the inspection method being used. Although there appears to be ample evidence of adequacy, a final report can only be issued when additional flight data is secured. Specifically, data is needed on Zone 9 flight range in which the spin velocity exceeds 11,000 rpm.

The inspection method is essentially a visual test based on comparative illustrative figures, included in the Operating Instructions, (see Ref 4). Because of the infinite variety of contours and areas that may be encountered, the figures are provided as guidelines only. At the present stage of implementation, this is considered the most feasible approach. In the future, it is felt that a more automated type decision-making process can be incorporated.

The inspection procedure essentially covers the existing requirements for minimum base-metal weld penetration by the welded overlay. It was instituted expeditiously to rectify an existing hardware problem.

As of July 1976, 1500 MIG-welded bands had been produced and inspected at the production facility with only one item being classified as marginally rejectable and only four having a minor unbonded area, which would still qualify as "Good" on a graded 6-level scale or mid-range in the acceptable category. The latter 4 served as the predicted process control in that a minor adjustment to the welding apparatus eliminated even this small unbond.

The data listed in this report indicates that the immediate goal of rectifying the hardware problem has been achieved.

The inspection method must now be further modified to incorporate the requirements of maximum base metal penetration and of cracks. This will accomplish a significant cost reduction by reducing the need for some of the destructive tests currently required.

CONCLUSIONS

1. The ultrasonic C-scan inspection for rotating band bond quality is a satisfactory and highly repeatable procedure.
2. Further flight data is required to ensure its value for substitution in lieu of existing destructive testing.
3. The ultrasonic inspection should be developed further to include other weld characteristics such as maximum penetration, base metal cracking, etc.

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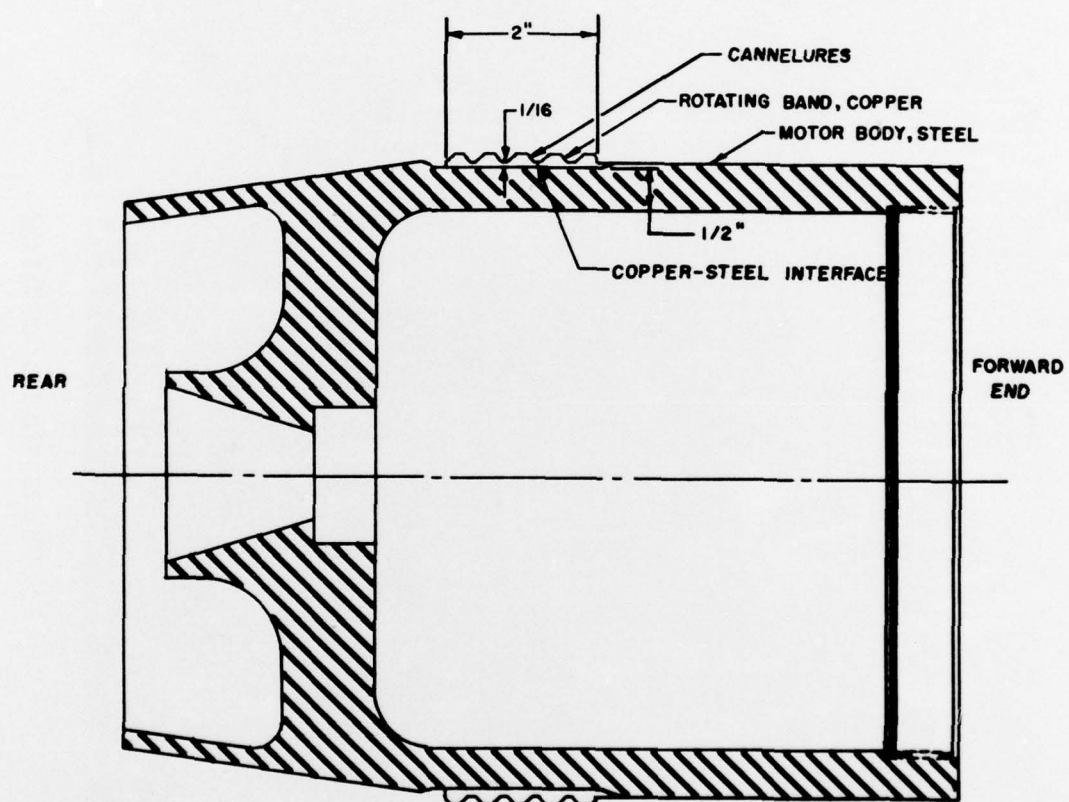


Fig 1 Cross section of XM650 RAP motor body
(welded overlay rotating band)

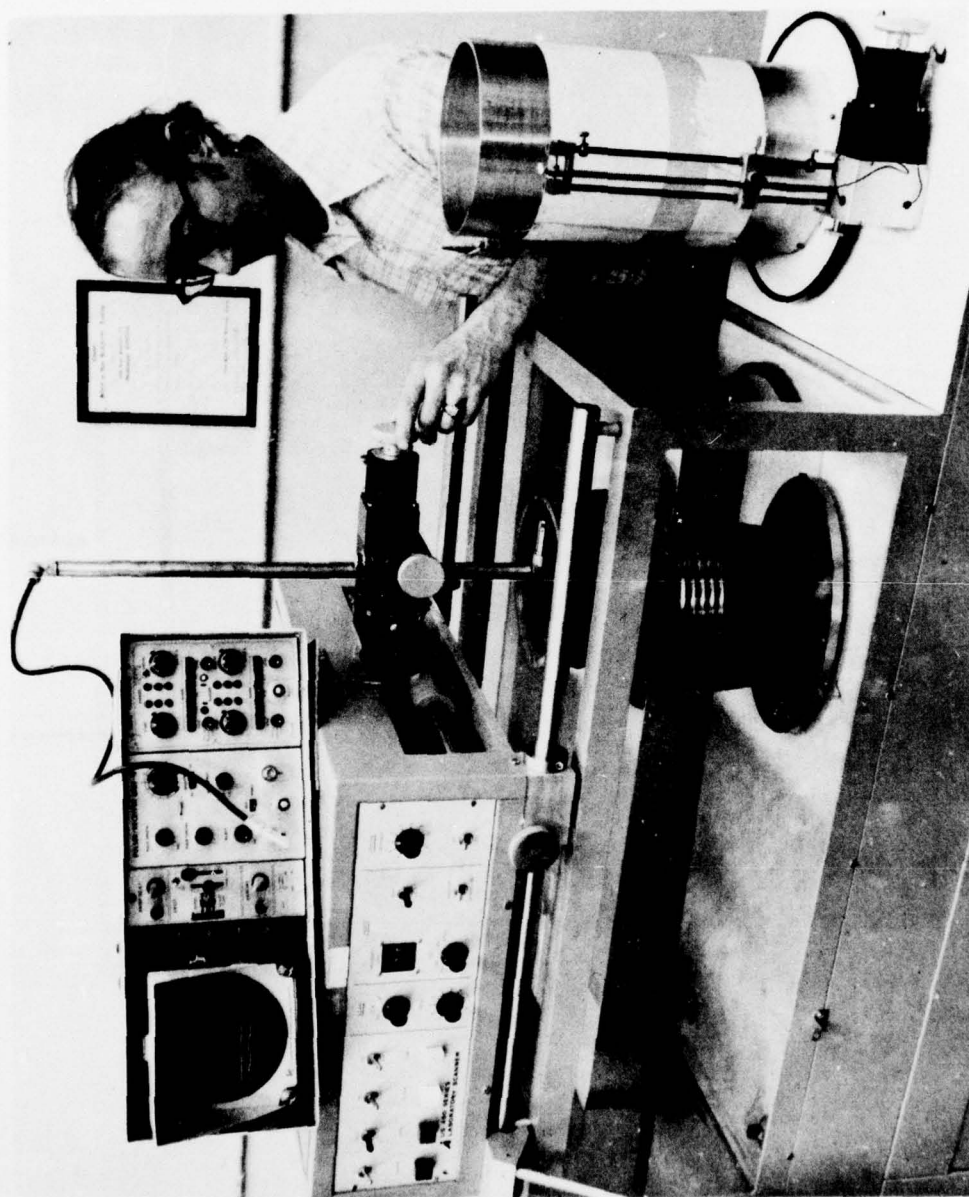


Fig 2 Ultrasonic C-scan System

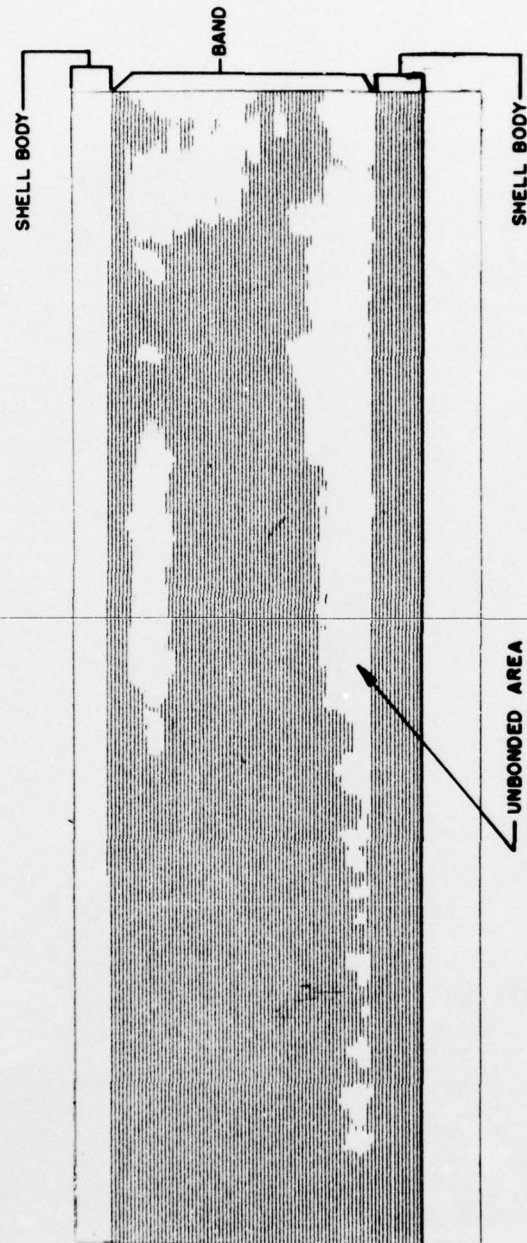


Fig 3 C-scan of a poorly bonded rotating band



Fig 4 Unbonded area - comparison of C-scan and
machined rotating band

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